Team Reports: Pennsylvania State University

Pennsylvania State University
Executive Summary
Principal Investigator: Hiroshi Ohmoto

The Evolution of a Habitable Planet

The Penn State Astrobiology Research Center (PSARC), created in 1998 as part of the NASA Astrobiology Institute, currently comprises 17 (Co)–PIs and their research teams from The Pennsylvania State University (Mike Arthur, Sue Brantley, Jean Brenchley, Will Castleman, Greg Ferry, Kate Freeman, Blair Hedges, Chris House, Jim Kasting, Lee Kump, Hiroshi Ohmoto, Mark Patzkowsky, Steinn Sigurdsson, and Alex Wolszczan), The University of Pittsburgh (Rosemary Capo and Brian Stewart), and SUNY Stony Brook (Martin Schoonen). During the period of July 1, 2003 – June 30, 2004 , PSARC has supported all or part of the research/education/PO activities carried out by 65 persons (17 (Co–)PIs, 7 research associates and postdoctoral fellows, 22 graduate students, 12 undergraduate students, 3 technicians, and 6 staff in administration/IT/EPO). In addition, 30 Associate Members for Research (who are mostly professors at other institutions) closely collaborate with the 17 (Co)–PIs. Two other Associate Members work closely with the EPO team.

Research

PSARC's research has focused on critical issues concerning *planetary habitability* : (1) the evolutionary history of the biosphere, hydrosphere, and atmosphere on Earth and other planets, specifically the times, causes, and consequences of the emergences of major organisms (e.g., cyanobacteria, methanogens, sulfate reducers, fermenters, sulfide oxidizers, and eukaryotes); (2) the effects of photochemical reactions on the early biosphere; and (3) detection of biosignatures on other planets. Our approaches to these critical issues, and some important achievements during the last year, are briefly summarized below:

I. Investigations of the Geochemical Record of the Earth's Early Biosphere. Freeman's group has found isotopic and molecular biomarker evidence for diverse microbial ecosystems (bacteria, archae, and eukaryotes) and “oxygen oases” in marine environments 2.8–2.5 Ga ago. Determination of an accurate age of a Precambrian paleosol has been difficult, but Capo–Stewart's group was successful in determining the ages of one of the oldest paleosols at Steep Rock , Canada (3.0 Ga) and of the oldest lateritic (ferric–iron enriched) soils at

Hokkalampi , Finland (2.35 Ga) by applying the Nd–Sm and Rb–Sr methods. Ohmoto directed the Archean Biosphere Drilling Project (ABDP), which drilled six deep holes during summer 2003 in the Pilbara district, Western Australia to recover modern–weathering–free rock sequences 3.5–2.7 Ga in age. Mineralogical and geochemical investigations of these rocks yielded evidence that microbes flourished in the oceans and that the atmosphere–ocean system was O_2 –and CO_2 –rich, but CH_4 –poor, during this period.

II. Investigations of Photochemical Reactions of Sulfur and Iron in the Early Earth. To understand the mechanism(s) for the creation of MIF of S isotopes and to aid in the reconstruction of the Precambrian S cycle using the isotope record in rocks, Castleman's group has initiated a series of photochemical reactions of SO_2 by utilizing a reflectron time–of–flight mass spectrometer (RETOF–MS) and a femtosecond laser system coupled with the pump–robe technique. They found an inverse kinetic isotope effect during the photolysis of 32 SO_2 and 34 SO_2 . From laboratory experiments at 35–150 °C, Schoonen's group has found that the hydrogen peroxide and OH radicals, produced by reactions between FeS 2 (pyrite) and water, could have limited the stability of RNA and/or have accelerated molecular evolution through mutagenesis in the early oceans. Kasting's group has made significant progress in coupled ecosystem/atmosphere modeling of the Archean Earth.

III. Investigations of Genomic Record of the Earth's Early Biosphere. Based on analyses of protein and DNA sequences of key organisms, Hedge's group produced a timescale for prokaryote evolution and found that complex multicellular life appeared about a billion years earlier than indicated by the fossil record. Using whole genomic analysis, House's group suggests that sulfur reduction is the most plausible early metabolism for the Archaea.

IV. Laboratory Microbial Simulations: Astrobiological Signatures. In order to relate the biogeochemical signatures in Precambrian rocks to specific organisms and environments, to understand the response of consortia of organisms to their environment, and to provide the references of biogenic gases in remote sensing of possible life–sustaining planets, our group (House, Arthur, Kump, Freeman, Ferry, Ohmoto and their students) has set up a series of microbial microcosms. Special foci are placed on the chemical and isotopic signatures of inorganic substrates, biogenic gases, and microbial lipids, and on the responses of anaerobes to oxygen and aerobes to methane and sulfide. From separate experiments, House's group has found that the Archaeoglobales cannot oxidize methane. Ferry' group has made significant advancement in understanding the effects on carbonic anhydrases (zinc enzyme) from *Methanosarcina thermophilica* of anaerobic reconstitution with Fe^{2+}, Fe^{3+}, Cu^{2+}, Mn^{2+}, Ni^{2+} and Cd^{2+}. To provide insight into the evolution of oxidative stress response strategies by early organisms, Lessner (a NAI post doc under Ferry) has been investigating the oxygen tolerance of *Methanosarcina acetivorans*. They have identified a gene cluster that encodes homologs of novel oxidative stress proteins. Brantley's group has continued to make progress in understanding the mechanisms various microbes extract metals (Fe, Mn, Zn, Ni, Co, and Mo) and P from minerals for their metabolic functions.

V. Investigations of Modern Analogues of Precambrian Microbial Ecosystems. Kump, Arthur, House and their students have initiated a comprehensive geochemical – microbial investigation of Fayetteville Green Lake , New York , as a modern analogue of the Proterozoic marine biosphere. Arthur's group has been investigating N isotope systematics in anerobic environments and at oxic/anoxic interface using the Black Sea and Fayetteville–Green Lake as Proterozoic analogues. Based on a thorough evaluation of biotic extinction record, Arthur and Hu Barnes (Associate Member) have suggested the following: major mass extinctions were caused by large bolide impacts or large igneous eruptions which occurred in carbonate– and sulfur–rich terrains and created large volatile fluxes. Patzkowsky has recognized that the Late Ordovician mass extinction probably occurred within 5 million years, rather than 20 million years as previously thought. Brenchley's group has discovered ultra–small microorganisms (< 0.2 micron size) in a 120,000–year–old Greenland–Glacier ice sample. This discovery is significant for at least two reasons: (1) the ultra–small organisms, previously undetected by normal filteration through the 0.2–micron pore size filters, are probably important constituents in all environments; and (2) microbes survival may be expected in ice on other planets.

VI. Investigations on Planetary Habitability and Life Detection. Sigurdsson's group discovered the oldest jovian planet (~12 Gyr) in a metal poor, distant stellar system. They have also found several candidate planets and low mass dwarfs around nearby DAZ starts. Wolszczan's group has initiated a search for planets around K–giants with the Hobby–Eberly telescope. Kasting's group, working in conjunction with Vikki Meadows' NAI group at Caltech/JPL, have made progress in understanding potential biomarkers on planets around F, G, K, and M stars. A collaboration between Kasting and David Pollard (PSU) has shed new light on the nature of Neoproterozoic Snowball Earth episodes and the question of how the photosynthetic biota survived these catastrophes.

Publications : During the period 7/1/03 – 6/30/04 , the PSARC (Co)–PIs (and their groups) published 45 papers (including those in press or accepted) in referred journals and books; 9 more are being reviewed by journals. They also published 53 abstracts of papers presented at national and international meetings.

Fieldwork : Geologic field work was conducted in: (a) the Pilbara district, Western Australia by Ohmoto and his students to conduct deep drilling under the Archean Biosphere Drilling Project (5 weeks, June–July 2003); (b) the Karelia and Kemi districts, Finland by Ohmoto and Watanabe to investigate ~2.35 Ga paleosols and ~2.0 Ga carbonates (10 days, June 2004); and (c) Fayetteville Green Lake, New York by Kump and students to investigate the microbial ecology and to collect water and microbial samples for laboratory simulators (1 week, July 2003).

Education and Public Outreach

Public Outreach: An annual Astrobiology workshop for high school teachers (~10 attendees) was held under the direction of Jim Kasting during the week of June 21 – June 25 2004 . Space Day at PSU, an annual one–day event to

showcase the exciting space−related research carried out at PSU, was held on April 17. PSARC faculty and graduate students exhibited posters describing their Astrobiology research and worked with the general public on hands−on experiments to increase the public's awareness of Astrobiology. The College of Earth and Mineral Sciences is undertaking of a major renovation of a building that will house a new museum with ~770 sq. feet of space devoted to Astrobiology exhibits. We have began designing the Astrobiology exhibits in close collaboration with Dr. Russell Graham, new museum director.

Undergraduate Education: Astrobiology Minor Program, established in Fall 2000, as inter−college undergraduate program, has attracted about ten students from the Departments of Geosciences, Astronomy, Microbiology, Biology, and Mathematics. It has been administered by Chris House. An undergraduate summer training program in astrobiology was established at Penn State , with the help of a 3−year NSF REU−Site award (Blair Hedges, PI). Last summer it supported 8 students (sophomores and juniors) from colleges and universities other than PSU to participate in research training under the PSARC PIs for a 10 week period.

Graduate Education: A Dual−Title Ph.D. Degree Program in Astrobiology, approved by the Faculty Senate in March 2004, will be inaugurated in August 2004 with a 10−day Astrobiology field trip to southern Canada for ~11 graduate students in this program. The dual−title program is under the direction of Lee Kump.

University Commitment : PSU's strong commitment to support NAI/PSARC programs continues with the hiring of two new tenure−track faculty positions in Astrobiology, one in Geosciences and the other in Biology. From a long list of strong candidates, we have selected Dr. Jennifer Macalady (geomicrobiologist from Carlton College) as a new Assistant Professor in Astrobiology in the Geosciences Department.